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(54) **Lead-free bearing bronze**

Bleifreies Lagermetall

Bronze pour paliers, ne contenant pas de plomb

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Cu Rest
Sn 4,55-9
Bi 3,54-9

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(56) References cited:
EP-A- 0 457 478
WO-A-91/14912
WO-A-94/04712
JP-A- 4 202 726
US-A- 4 551 395

- **Chemical Abstract: vol 96. no. 16, p. 351, Abstract No. 128144**

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Description

Background of the Disclosure

This invention related to a lead-free continuously-cast copper-base alloy suited for use as a bearing, bushing, or guide material.

Currently there are different specifications covering many bearing bronzes, the most popular of them being those of Copper Development Association (CDA). Some of these bearing bronzes are lead-free, for example, C903 or C954. Others are leaded, for example, C932 and C936. Lead-free bronzes like C903 and C954 have high coefficient of friction in metal to metal rubbing contact and also have lower machinability compared to leaded bronzes.

Leaded bronzes have good machinability and have low coefficient of friction. However, they contain anywhere from 5 to over 15 percent lead in them. During the past two decades it has been established that ingestion of even a few parts per billion of lead into human body causes severe health problem. As a consequence strong efforts are being made to eliminate lead from materials which ultimately might end up in human beings. Recently considerable efforts have been made to remove or at least reduce the lead content from plumbing brasses that come in contact with potable water. U.S. Patent No. 4,879,094 is an example.

In bearing and bushing bronzes lead is used primarily as a lubricating agent which also helps machinability. Currently there are many pump installations handling water that contain leaded bearings. Lead from them can possibly contaminate water being pumped. Furthermore, many machine shops buy lead containing bars and tube stocks to machine them into bushings and bearings. This might expose machinists to lead-bearing dusts if not fully protected. Additionally, lead-bearing scrap requires proper handling and recycling to prevent lead from entering the environment.

This establishes the need for a low friction bearing alloy which does not contain any highly toxic material like lead. In fact, there already are some lead-free alloys with low friction. Examples are nickel-base alloys of Thomas and Williams (U.S. Patent No. 2,743,176) and of Larson (U.S. Patent No. 4,702,887) and copper-nickel alloy of Sahu (U.S. Patent No. 5,242,657). However, these alloys are many times more expensive than common bearing alloys like C932 and C936.

Lead-free, bismuth alloged copper base alloys made by PM are known in the art, eg. WO-A-94/04712 and WO-A-91/14912.

Summary of the Invention

The invention is defined in the claims.

This alloy may contain small amounts of C, Si, Fe, Mn, Al, and other elements as incidental or trace elements. Zinc may be present in some scrap metal sources used for the melt and can be tolerated in amounts up to about 1% by weight.

When the ingredients are mixed in approximately the preferred analysis the following data will describe its physical properties.

Tensile Strength	30,000 - 45,000 psi
Yield Strength	18,000 - 28,000 psi
Percent elongation in 2"	10.0 - 25.0
Brinell hardness	65 - 95

Brief Description of the Drawings

Fig. 1 is a graph showing the coefficient of friction versus pressure velocity for various alloys;
Fig. 2 is a perspective view of a bearing/bushing test fixture;
Fig. 3 is a perspective view of a pin on disc galling test apparatus;
Fig. 4 of the drawings shows a lathe cutting operation;
Fig. 5 is a perspective view of machinery parts in which the present invention may be embodied;
Fig. 6 is a perspective view of parts made in permanent molds in which the present invention may be embodied;
Fig. 7 shows sand molded parts which may be molded with the alloy of this invention;
Fig. 8 shows the use of bearings made in accordance with the teachings of this invention;
Fig. 9 is a perspective view of a sluice gate assembly for a water reservoir utilizing the alloy of this invention; and
Fig. 10 is a gyroscopic cone crusher using bearings made in accordance with the teachings of this invention.

Description of the Preferred Embodiments

In its methods aspects the alloy can be melted in a gas fired crucible or an electric induction furnace. Copper is charged into the melting bessel and when it is completely molten, the slag on the top is drawn to one side and tin, bismuth and phosphorus-copper shot are added to the melt.

The melt is transferred into a bottom tapped holding crucible where it is fed through a graphite die to form a continuously cast solid, tube or other shape as desired. Test samples were prepared this way. In addition, the melt may be tapped into a variety of molds such as sand, steel or graphite to obtain the castings of desired shape.

The chemistry of five heats continuously cast into bars and tubes are as given in Table 1. Also included in this table, for the sake of comparison, are two current leaded bearing bronzes, (C932 and C936) amd two current lead-free bronzes (C954 and C903). Chemistries and physical properties reported for C932, C936, C954 and C903 are nominal as published by Copper Development Association.

TABLE 1:

Chemistry of Bearing Bronzes (Percent by weight)										
Alloy ID	Cu	Sn	Pb	Zn	Bi	Ni	P	Al	Fe	Remarks
C932	83	7	7	3	--	--	--	--	--	Leaded Bronze
C936	80	7	12	1	--	--	--	--	--	Leaded Bronze
C954	85	--	--	--	--	--	--	11	4	Lead-free Bronze
C903	88	8	--	4	--	--	--	--	--	Lead-free Bronze
BI-4	Bal	6.14	--	--	3.81	.03	.06	--	--	Bismuth Bronze
6BI	Bal	5.02	--	--	5.32	.01	.01	--	--	Bismuth Bronze
6BIP	Bal	4.85	--	--	5.29	.01	.09	--	--	Bismuth Bronze
8BIZ	Bal	7.51	--	.08	5.32	.01	.01	--	--	Bismuth Bronze
8.5BI	Bal	8.41	--	--	6.34	.01	.03	--	--	Bismuth Bronze

Mechanical Properties of the above alloys are given below:

TABLE 2:

Mechanical Properties of Bearing Bronzes				
Alloy ID	Tensile Strength, psi	Yield Strength, psi	% Elongation in 2"	Hardness BHN
C932	35,000	18,000	20.0	65
C936	35,000	21,000	15.0	65
C954	85,000	35,000	18.0	170
C903	45,000	21,000	30.0	70
BI-4	40,200	21,800	23.0	72
6BI	31,000	20,100	10.5	72
6BIP	35,900	19,000	20.0	73
8BIZ	35,900	23,100	13.5	80
8.5 BI	44,100	25,300	17.5	89

Comparison of mechanical properties of five heats of lead-free alloy with standard alloys (C932 and C936) indicates that the new alloy has properties comparable to the current alloys. Besides, the strength and elongation can be adjusted within limits by adjusting the percentage of tin and phosphorus in the alloy.

FRICTION PROPERTIES

The most crucial property of a bearing/bushing alloy is its low coefficient of friction (static and dynamic) in dry and marginally lubricated condition. The dynamic test was run according to modified ASTM D3702 method. Rings of standard alloy (C932 and C936) and the new alloy (6BI, 8BIZ, and 8.5 BI) were run against hardened (56 RC) 440C stainless steel washers at room temperature in distilled water. Coefficients of friction (C.O.F.) were measured for given PV values and are given Table 3 below and also plotted in Fig. 1. Pressure P is measured in pounds per square inch and velocity V is measured in feet per minute. The product function PV is a measure of severity to which specimen is subjected

during the test. The higher the PV value, the more severe the loading.

TABLE 3:

Coefficient of Friction at Various PV Values								
Alloy	PV=6250	PV=12,500	PV=18,750	PV=25,000	PV=31,250	PV=37,500	PV=43750	Average
C932	.236	.272	.286	.277	.271	.251	.257	.264
C936	.240	.262	.262	.275	.268	.245	.264	.259
6BI	.278	.290	.299	.322	.319	.321	.317	.307
8BIZ	.278	.320	.331	.343	.337	.335	.317	.323
8.5BI	.166	.251	.295	.330	.356	.339	.319	.293

Two specimens were run for each of the above alloys and the average of two values has been reported above. It should be mentioned here that even at the highest PV value tested none of the above alloys showed any signs of galling. In industrial applications, bearings will rarely see values of PV greater than 40,000 and certainly not in marginal lubrication. It is seen from Tabel 3 that the standard alloy (C932 and C936) has an average C.O.F. of 0.26 and the new alloy (6BI, 8BIZ, and 8.5 BI) has an average C.O.F. of 0.31. Even though friction value for the new alloy is slightly higher than that of standard alloy, it is still low and perfectly acceptable. Leaded dairy metal bearings/bushings which have worked satisfactorily in the field can have friction values of 0.45 (U.S. Patent No. 5,242,657).

Statis friction test was run on a simulated bearing/bushing test fixture shown in Figure 2. Hardened steel sleeve S is keyed to the shaft B which passes through two roller bearings in pillow blocks C. The pillow blocks are rigidly fastened ot the base D. Bronze sleeve bushing A is slipped over the hardened steel sleeve and there is only 0.002" diametrical clearance between the two. The bushing is surrounded by two half blocks E and F, the internal contours of which matches that of the bushing to be tested. A load cell G mounted on block E has a cylindrical rod extending from its bottom portion. The spherical end of this rod passes through a hole in block E and touches a machined seat on the test bushing. There is a threaded bolt H on the top of the load cell having a nut K. By turning the nut the bolt H can be moved up or down. Bolt H touches the cross-bar L which is rigidly fastened to the base frame. The load generated by turning nut is transmitted through the block E to the bushing A and is read off the load-cell dial M. A calibrated torque wrench T attached to one end of the shaft B is used to turn the shaft.

Steel sleeve S and the bushing A were thoroughly cleaned and degreased before installing on the test fixture. The bushing has an internal diameter (ID) of 2.125 inches, outer diameter (OD) of 2.750 inches and a length 2.1875 inches. The length of steel sleeve was 3 inches and extended on both sides of the bushing equally. During the experiment a load P of 500 lbs was applied to the bushing and the torque required to rotate the shaft, T, at 1 to 2 RPM was measured. The valve of static coefficient of friction is thus T/1.0625P. The load was increased to 750 lbs and again the torque required to rotate the shaft at slow speed was measured. Subsequently, the load was increased to 1000 and 1250 lbs and corresponding values of torque were measured. Next the load was decreased to 1000, 750, and 500 lbs. in successive steps and corresponding values of torque measured. Thus for a single bushing seven values of C.O.F. were calculated - four during loading and three during unloading. The maximum spread in values of C.O.F. for a single bushing was 0.04. The average of these seven values is reported in the following table. Five bushings from each alloy were tested and the results are given in Table 4.

TABLE 4:

Statis Coefficient of Friction for Bearing Bronzes						
Alloy ID	Statis Coefficient of Friction for Bearing Bronzes					
	Spl 1	Spl 2	Spl 3	Spl 4	Spl 5	Average
C932	.17	.16	.20	.19	.18	.18
C936	.17	.20	.19	.13	.19	.18
6BI	.19	.12	.17	.14	.21	.17
6BIP	.21	.13	.20	.21	.19	.19
8BIZ	.23	.21	.24	.22	.19	.22
8.5BI	.19	.18	.19	.19	.17	.18

It can be seen from the above table that the average statis coefficient of friction for the new alloy (7BI, 6BIP, 8BIZ and 8.5BI) is comparable to those of the standard alloys (C932 and C936).

Bronze bushings and bearings are also designed to be a sacrificial item. In other words, they should wear out preferentially leaving the shaft or journal unaffected. During modified ASTM D-3702 friction test weight loss of bearing materials as well as the hardened steel was measured and the results are given below. It should be noted here that each value is average of two readings.

TABLE 5:

Weight Loss During Ring on Washer Test (D-3702)		
Alloy ID	Average Weight loss, mg, for Rings	Average Weight Loss of Mating Hard 440 C Washer, mg
C932	179	1
C936	117	1
6BI	122	1

TABLE 5: (continued)

Weight Loss During Ring on Washer Test (D-3702)		
Alloy ID	Average Weight loss, mg, for Rings	Average Weight Loss of Mating Hard 440 C Washer, mg
8BIz	268	(2)*
8.5 BI	87	(1)*

* Weight gain due to transfer of metal from ring to washer

It is seen from the above table that all bushing materials, new as well as standard, wear out two orders of magnitude faster than the hard steel mating part.

WEAR PROPERTIES

Pin-on-disc apparatus was used to run wear test per modified ASTM G-99 specification. Figure 3 shows the pin-on-disc arrangement. Bearing bronze pins were loaded against a disc (316 SS or 440C) which rotated at a speed of 101.5 RPM. The 316 SS disc had a hardness of around 170 BHN and 440C disc had a hardness of 56 RC. The load applied to the pin was either 42.5 pounds or 32.5 pounds giving PV values of 9420 and 7204 respectively. The disc and the lower portion of the pin were immersed in water. The duration of the test was one hour. It should be noted that the disc surface was sanded on 80 grit paper and the pin end was sanded on 250 grip emery paper.

At the end of the test both contacting surfaces were examined for any sign of galling and it was found that there was no galling on either surface. The weight loss of the pin was calculated from its initial and final weights. Two specimens were tested for each condition and the average results are given in the tables below.

TABLE 6:

Weight Loss of Bearing Bronze Against 440C		
Alloy ID	Average Weight Loss of Pin, Grams	
	PV=9420	PV=7204
C932	.104	.105
C936	.164	.097
BI4	.187	.206
6BI	.232	.155
6BIP	.195	.148
8BIZ	.155	.091
8.5BI	.103	.081

TABLE 7:

Weight Loss of Bearing Bronze Against 316 SS		
Alloy ID	Average Weight Loss of Pin, Grams	
	PV=9420	PV=7204
C932	.138	.117
C936	.148	.144
BI4	.176	.154
6BI	.177	.151
6BIP	.299	.132
8BIZ	.116	.093
8.5BI	.082	.063

It can be seen from the above tables that the new alloy has wear rate comparable to standard alloys C932 and C936. As a matter of fact alloys like 8BIZ and 8.5BI have much less wear than C932 and C936.

MACHINABILITY AND SURFACE FINISH

Machinability and surface smoothness of an alloy is very important in determining the cost of the finished product. Faster the alloy can be machined, the lower the cost of the end product. For products like bearings and bushings the maximum surface roughness is given by the established specification. In order to get a better surface finish the depth of cut and/or the feed rate are reduced providing all other parameters including the type and geometry of the cutting tool are fixed.

During present invention. the machinability was measured using a tool post dynamometer on a conventional lathe. For the turning operation, the x, y, and z components of the force were measured as shown in Fig. 4. The net force F was taken as the square root of the sum of x, y and z components squared.

$$F=(fx^2 + fy^2 x fz^2)^{1/2}$$

The diameter of the bar was 1.46 inches, rotational speed 360 RPM, depth of cut 0.010 inches and the feed rate was 0.005 inches per revolution. The roughness of the machined surface was also measured with a profilometer. Four samples from each alloy were tested for machining force and the surface finish. The average of these readings are presented below.

TABLE 8:

Machinability and Surface Finish of Bearing Bronzes			
Alloy ID	Machining Force, lbs.	Machinability Rating	Surface Finish Microinch
6BIP	9.3	90	39
BI4	10.7	78	36
C936	10.9	76	41
C932	11.9	70	41
8BIZ	12.5	67	37
8.5BI	15.1	55	39
6BI	17.1	49	55
C954	18.0	46	27
C903	21.4	39	213

For comparison purposes two lead-free bearing bronzes, namely, C954 and C903 were included in machinability studies. Of these C954 is an aluminum bronze and C903 is a tin bronze. The force required to machine a part is a measure of machining difficulty. Lower machining force means better machinability. For ease in comparison the machinability of C932 was given a number of 70 to match the value given in the CDA handbook. Column 3 in Table 8 gives machinability of other alloys. It is seen in this column that machinability of bismuth bearing alloys, namely, 6BIP, B14, 8BIZ, 8.5BI, and 6BI ranges from 90 down to 49 with an average of 68. In other words bismuth-bearing bronzes have machinability comparable to C932. In any case, the main aim, of the present invention is removal of lead from the alloy and machinability is of secondary importance.

As can be seen from column 4 in Table 8 the surface finish of bismuth-bearing alloys is similar to those of C932 and C936. As a matter of fact, the average finish of five bismuth-bearing alloys is identical to C932/C936. Surprisingly, C903 had a much rougher surface.

CASTABILITY

Castability of bismuth-bearing bronze was similar to leaded bronze. The speed with which continuously cast bar or tube could be withdrawn from the die was same as that of leaded bronze. The cast bars had good surface finish and cross-sections were fully sound and defect-free. In summary, there is no difference between castabilities of leaded and bismuth-bearing bronzes.

CORROSION

The corrosion resistance of a bearing alloy iin different environments is very important. In use the bearing/bushing encounters gaseous or liquid corrodants. For example, in oil drilling the bushing will see sour gas (H_2S), near sea

shore it will encounter salty water and in the paper and pulp mill the part will see paper mill fluid. In order for the new alloy to replace current leaded bronze, the new alloy must have corrosion resistance comparable to or better than the current alloy. The following four solutions were selected to compare the corrosion resistance of new and current bearing bronzes.

1. 5 weight percent of sodium hydrozide (NaOH) in water.
2. Simulates Eat Water: This was prepared by dissolving 3 weight percent sodium chloride (NaCl) and 0.5 weight precent sodium sulphate (Na_2SO_4) in water.
3. Simulated Paper-Mill liquid: This was prepared by adding to one liter of water the following amounts of different chemicals.

   NaCl = 0.655 gram
   Na_2SO_4 = 5.917 gram
   $Na_2S_2O_3$ = 0.063 gram
   Na_2S0_{23} = 0.132 gram

4. Sour gas (H_2S) Solution: One liter of this solution had 995 mililiter of water and 5 mililiter of concentrated acetic acid. This solution was saturated with H_2S by constantly bubbling the gas through the solution.

The corrosion test was run according to ASTM Spec. G31-72. The specimen was in the from of a circular disc with nominal OD=1.25", ID=0.375" and thickness = 0.187". The specimen was properly prepared and its dimensions and weight were measured. The specimen was put inside a one liter solution of one of the above compounds in a widemouth flask. All of the solutions except the sour fas (H_2S) was kept at 50 degrees C and mildly agitated with a magnetic stirrer. Sour gas (H_2S) solution was kept at ambient temperature and the agitation was provided by gas bubbles. The specimen was kept in the solution for 48 hours. At tne end of this period, the specimen was taken out, washed thoroughly and re-weighed. From the weight loss and dimensions of the specimen the corrosion rate in mils per year was calculated. Duplicate specimens were run for each condition and the reported corrosion rate is average of the two readings. The following table lists the details:

TABLE 9:

Corrosion Rate of Bearing Bronze in Mils per Year				
Alloy	NaOH	Sea Water	Sour Gas, H2S	Paper Mill Soln.
C932	46.1	7.1	2.9	5.3
C936	54.1	6.3	0.3	4.3
BI4	36.6	7.6	0.9	6.3
6BI	36.5	6.6	1.2	3.9
6BIP	51.8	7.3	1.5	5.3
8BIZ	40.0	8.1	0.8	3.5
8.5BI	59.9	7.5	0.4	4.9

Generally speaking a corrosion rate of less than 20 mils per year is considered good. On this basis, both standard leaded bronze (C932 and C936) and all new bismuth-bearing alloys have good corrosion resistance in sea water, sour gas and paper-mill solution. In 5% NaOH solution, the corrosion resistance of standard alloys as well as new alloys is marginal. However, the average corrosion resistance of the new alloy (BI4, 6BI, 6BIP, 8BIZ and 8.5BI) is as good as standard alloys (C932 and C936).

In bearing bronzes zinc has a tendency to selectively leach-out in many environments. This phenomenon is referred to as "dezincification". This can be seen by comparing the corrosion rates of C932 and C936 in sour gas (H_2O) solution. The alloy of the present invention, for this reason, does not contain any zinc in it.

Parts machined from continuously cast new alloy can have numerous variations in shape, size and design. A few of them are shown iin Figure 5. These include bushings, bearings, pulleys, thrust washers and guide tube. The new alloy can also be poured into permanent molds made of steel, graphite, etc., to get the parts of desired shape and size. Two examples of these are shown in Figure 6; one is a large size, say 24 inch ID, standard flanged bushing and the other is a lantern bushing of a similar size. Further, the new alloy may be poured in regular sand mold to get parts of desired shape and size. Some examples of these are shown in Figure 7.

Three examples of typical arrangements in which the present alloy may be embodied are shown in Figures 8, 9, and 10. Figure 8 depicts one end of a transmission shaft (journal) through which power is transferred from a power

source, say an electric motor, to other mechanisms. The steel shaft 3 passes through the bronze sleeve bushing 2 made from the new alloy. This bushing is held in place by the bearing housing 1 made of standard steel or iron. There is no relative motion between bearing 2 and the housing 1. There is small gap 4 between the hournal 3 and the bearing 2 which contains a lubricant, heavy oil or grease, supplied through the access hole 5. During operation, the journal 3 rotates inside the bronze bearing 2 and the load W is transmitted through the lubricant to the bearing to the housing and ultimately to the building structure. In case of temporary lubricant failure the bearing 2 has enough in-build lubrication because of dispersed bismuth pools in the matrix that the hournal does not get scuffed or damaged.

Figure 9 depicts a sluice gate assembly for a water reservoir. The frame 3, guide 4, stem 7, and gate 8 may be constructed out of wrought carbon steel. Bronze seat facing 9 may be made out of present alloy. The steel frame 3 is secured to concrete wall 1 by anchor bolts 2. The guide 4 is permanently attached to frame 3. During operation when gate 8 is lowered by mechanized stem 7, the gate is led into the proper position by gate guide 6 moving through the guide slot 5. The design of the assembly is such that as the gate goes down the bronze seat facings 9 get closer and closer to the machined face of frame 3. By the time the gate is completely down the bronze seat facings seat tightly against the frame completely closing the water flow.

Figure 10 depicts a gyrasphere crusher used in crushing of mining aggregates. The motion of spherical crushing head 1 is effected through a combination actions of eccentric 2 driven by gear 3 and spindle 4 with help from cams and rollers not shown in the figure. Bronze bushing 5 is fastened to eccentric 2. During crusher operation eccentric 2 moves around spindle 4 and the bushing 5 reduces the friction between the two moving parts.

While there is reference specifically to mechanical elements in the form of bushings, bearings and guides, the term "bushing" is taken herein as generic to all such elements.

Claims

1. A copper-tin low-friction bronze alloy containing, besides tin and copper, quantities of bismuth, wherein the alloy is in the form of a casting and consists of the following elements in weight percentage range :

   Sn = 4.85-9
   Bi = 3.81-9
   P = 0-0.3
   Zn = 0-1
   Ni - 0-2
   Pb = 0.35
   Cu = Balance, apart from impurities.

2. A casting according to claim 1 which consists of the following elements in weight percentage :

   Sn = 7
   Bi = 5
   P = 0.10
   Cu = Balance, apart from incidental elements.

3. An industrial application in which opposed members are in moving contact with one another, characterised in that one of the opposed members is a casting according to claim 1 or claim 2.

4. An industrial approbation in which opposed members are in contact with one another characterised in that one of the opposed members is a casting according to claim 1 or claim 2 and the other opposed member is of steel.

5. A mechanical installation having a journal member and a bushing member, characterised in that the bushing member is a casting according to claim 1 or claim 2.

6. A sluice gate assembly having a frame and a gate characterised in that a seat facing of the gate is a casting according to claim 1 or claim 2.

7. A gyrasphere crusher having a spindle and an eccentric, characterised in that a sleeve facing of the eccentric is a casting according to claim 1 or claim 2.

Patentansprüche

1. Reibungsarme Kupfer-Zinn-Bronzelegierung, die neben Zinn und Kupfer Mengen an Wismut enthält, wobei die Legierung die Form eines Gußstücks hat und neben Verunreinigungen aus den folgenden Elementen im Gewichtsprozentbereich besteht:

   Sn = 4,85 - 9
   Bi = 3,81 - 9
   P = 0-0,3
   Zn = 0 - 1
   Ni = 0-2
   Pb = 0 - 0,35
   Cu = Rest.

2. Gußstück nach Anspruch 1, das neben zufälligen Begleitelementen aus den folgenden Elementen in Gewichtsprozent besteht:

   Sn = 7
   Bi = 5
   P = 0,10
   Cu = Rest.

3. Industrielle Einsatzform, bei der einander gegenüberliegende Elemente beweglich miteinander in Kontakt sind, **dadurch gekennzeichnet,** daß eines der einander gegenüberliegenden Elemente ein Gußstück nach Anspruch 1 oder Anspruch 2 ist.

4. Industrielle Einsatzform, bei der einander gegenüberliegende Elemente miteinander in Kontakt sind, **dadurch gekennzeichnet**, daß eines der einander gegenüberliegenden Elemente ein Gußstück nach Anspruch 1 oder Anspruch 2 ist, und das andere gegenüberliegende Element aus Stahl besteht.

5. Mechanische Installation mit einem Lagerelement und einem Buchsenelement, **dadurch gekennzeichnet**, daß das Buchsenelement ein Gußstück nach Anspruch 1 oder Anspruch 2 ist.

6. Schleusentorbaugruppe mit einem Rahmen und einem Tor, **dadurch gekennzeichnet**, daß eine dem Tor zugewandte Aufnahme ein Gußstück nach Anspruch 1 oder Anspruch 2 ist.

7. Kreiselbrecher mit einer Spindel und einem Exzenter, **dadurch gekennzeichnet**, daß eine dem Exzenter zugewandte Hülse ein Gußstück nach Anspruch 1 oder Anspruch 2 ist.

Revendications

1. Alliage de bronze antifriction au cuivre-étain contenant, outre l'étain et le cuivre, une certaine quantité de bismuth, dans lequel
   l'alliage se présentant sous la forme d'un moulage constitue des éléments ci-après dans les plages de pourcentages de poids suivantes :

   Sn = 4,85 - 9
   Bi = 3,81 - 9
   P = 0 - 0,3
   Zn = 0 - 1
   Ni = 0 - 2
   Pb = 0 - 0,35
   Cu = complément à 100 %, à part les impuretés.

2. Moulage selon la revendication 1,
   constitué
   des éléments ci-après dans les pourcentages de poids suivants :

Sn = 7
Bi = 5
P = 0,10
Cu = complément à 100 %, indépendamment d'éléments fortuits.

3. Application industrielle dans laquelle des éléments opposés sont en contact de mouvement les uns par rapport aux autres,
caractérisée en ce que
l'un des éléments opposés est un moulage selon la revendication 1 ou la revendication 2.

4. Application industrielle dans laquelle des éléments opposés sont en contact les uns avec les autres,
caractérisée en ce que
l'un des éléments opposés est un moulage selon la revendication 1 ou la revendication 2 tandis que l'autre élément opposé est en acier.

5. Installation mécanique comportant un élément de tourillon et un élément de coussinet,
caractérisée en ce que
l'élément de coussinet est un moulage selon la revendication 1 ou la revendication 2.

6. Ensemble de porte d'écluse comportant un châssis et une porte,
caractérisé en ce qu'
un siège faisant face à la porte est un moulage selon la revendication 1 ou la revendication 2.

7. Broyeur à sphères tournantes comportant un arbre et un excentrique,
caractérisé en ce qu'
un manchon faisant face à l'excentrique est un moulage selon la revendication 1 ou la revendication 2.

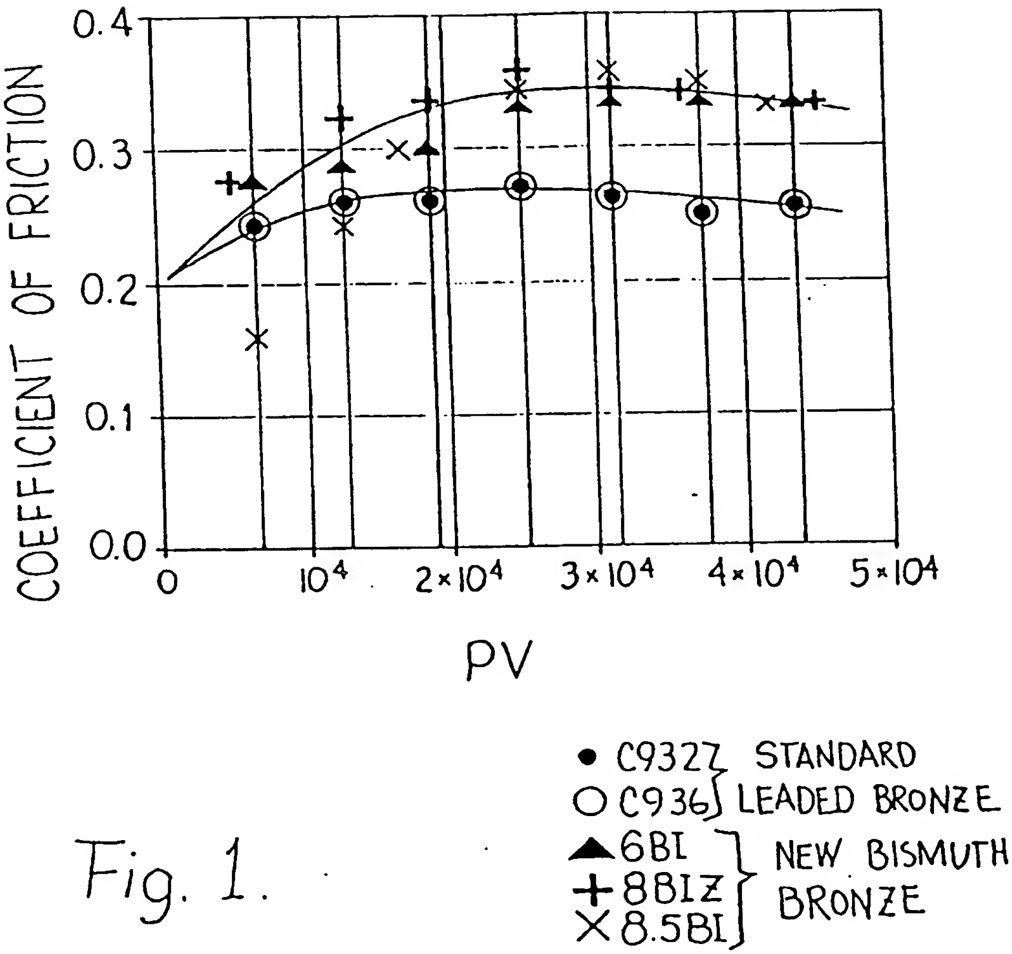
0.4
0.3
0.2
0.1
0.0
COEFFICIENT OF FRICTION
0
10⁴
2×10⁴
3×10⁴
4×10⁴
5×10⁴
PV
C932
C936
STANDARD LEADED BRONZE
6BI
8BIZ
8.5BI
NEW BISMUTH BRONZE

Fig. 1.

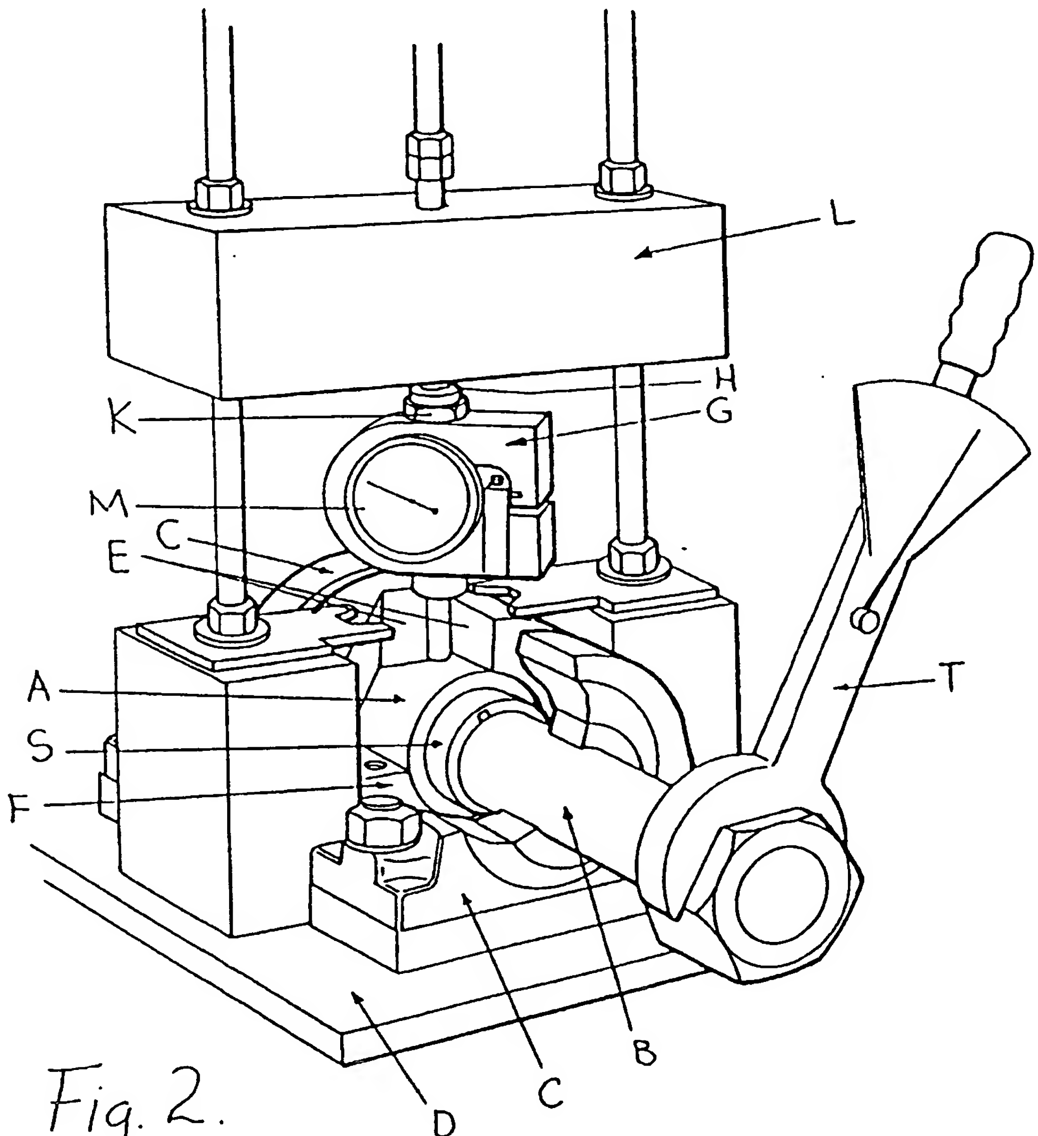

Fig. 2.

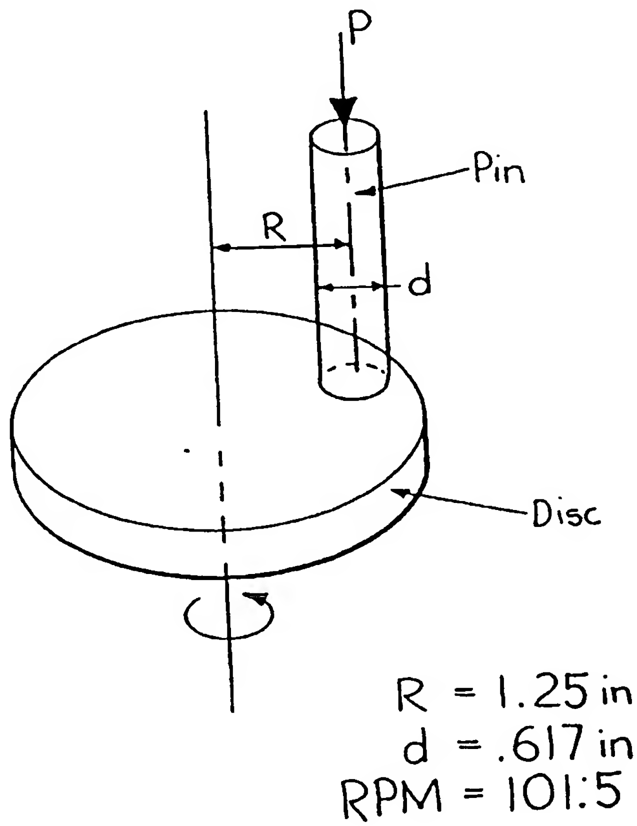

Fig. 3.

$$F = \sqrt{f_x^2 + f_y^2 + f_z^2}$$

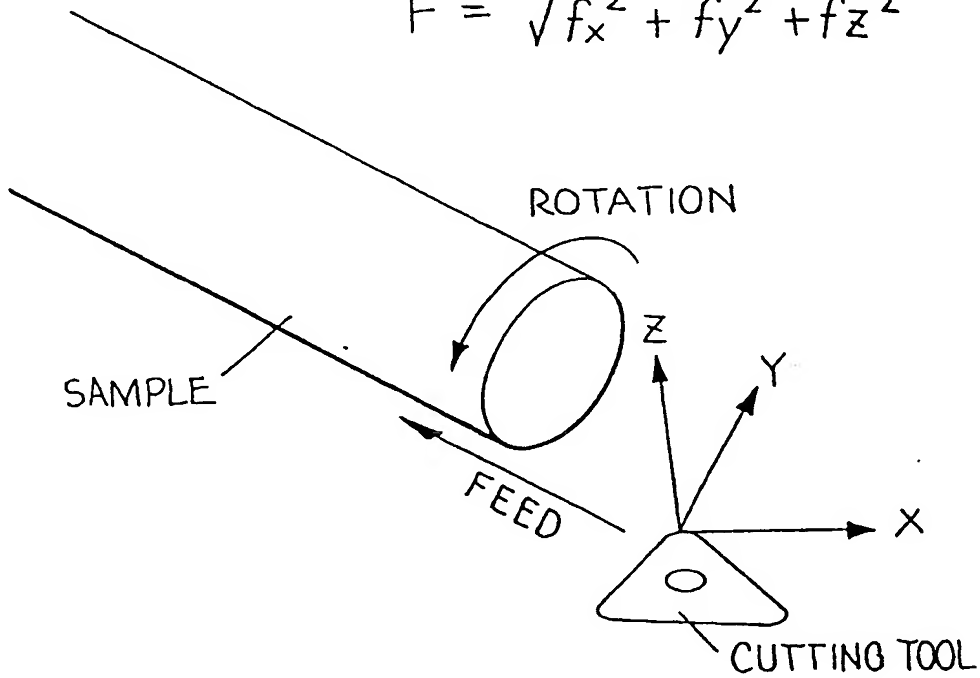

Fig. 4.

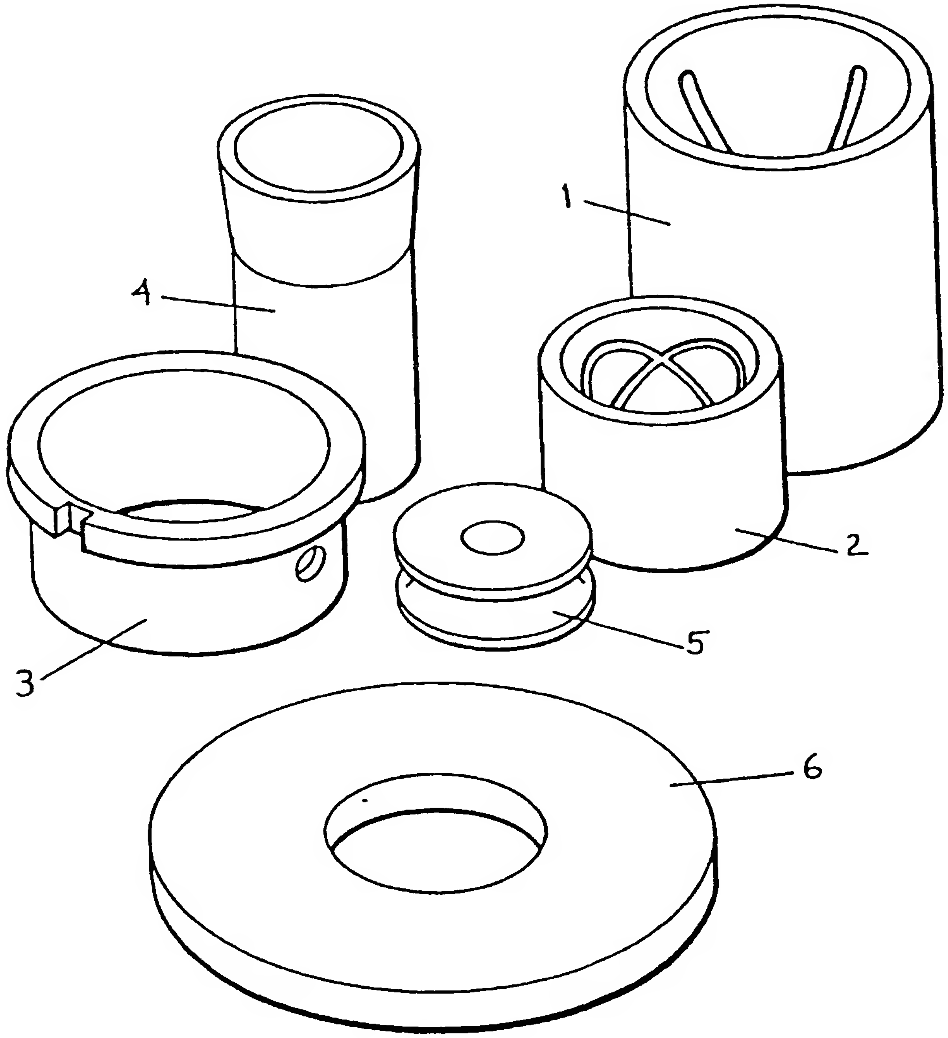

Fig. 5.

1, 2 - BUSHINGS WITH OIL GROOVES
3 - FLANGED BUSHING
4 - GUIDE TUBE
5 - PULLEY
6 - THRUST WASHER

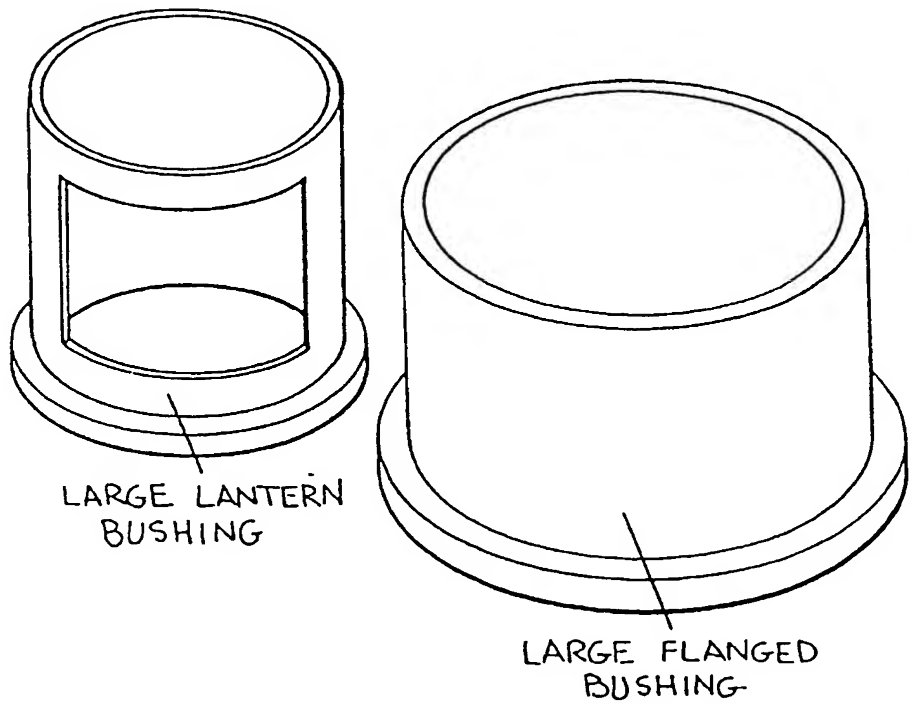

Fig. 6.

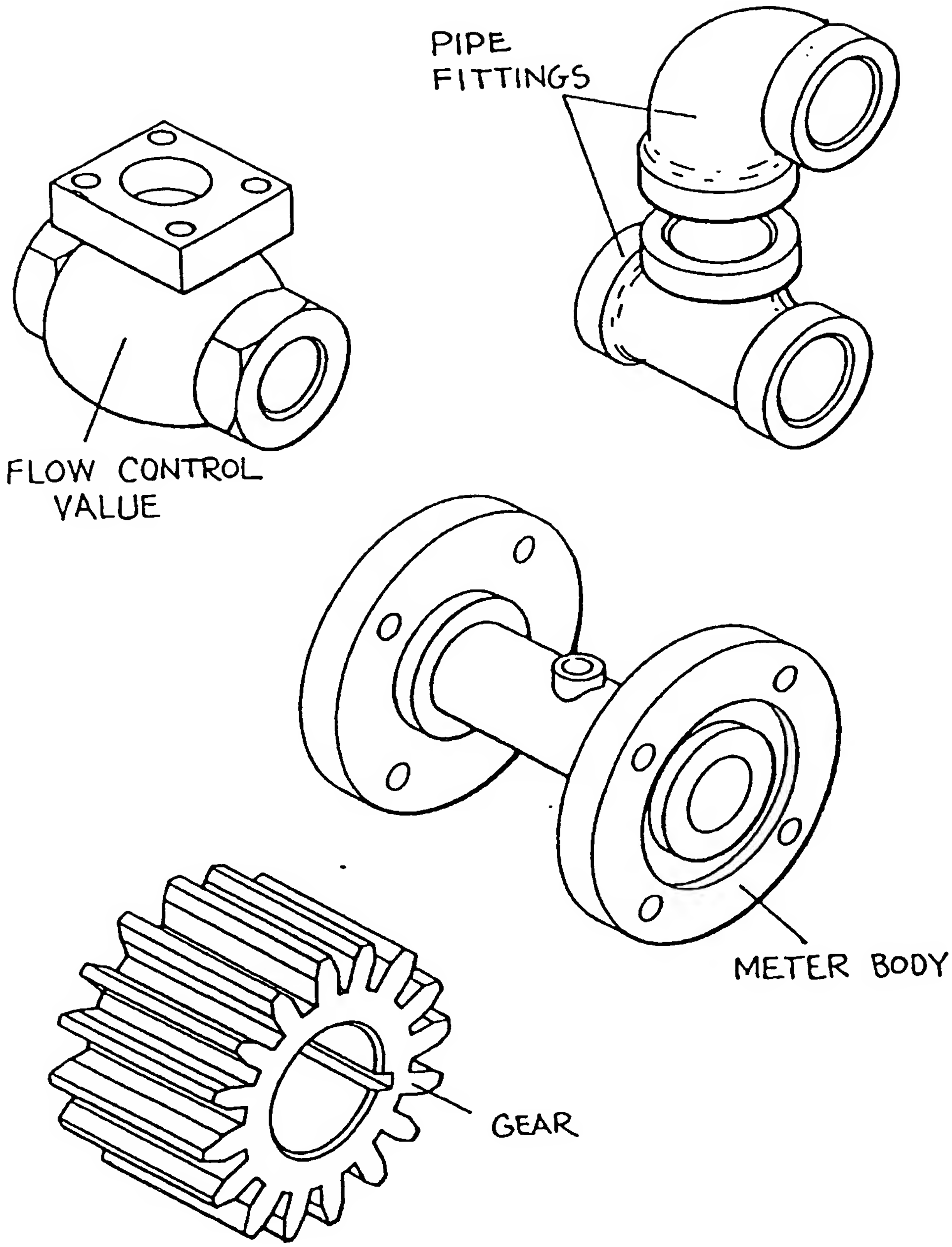

Fig. 7.

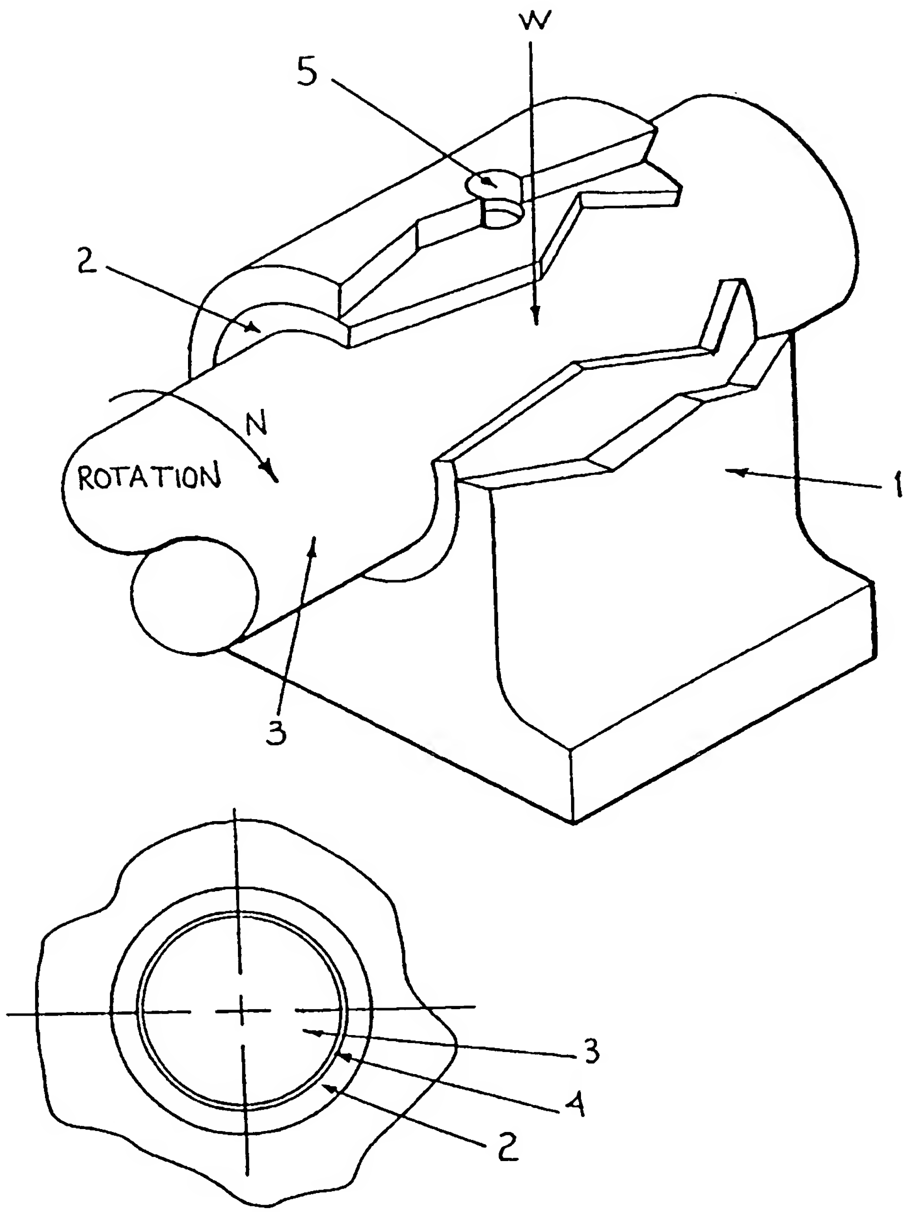

Fig. 8.

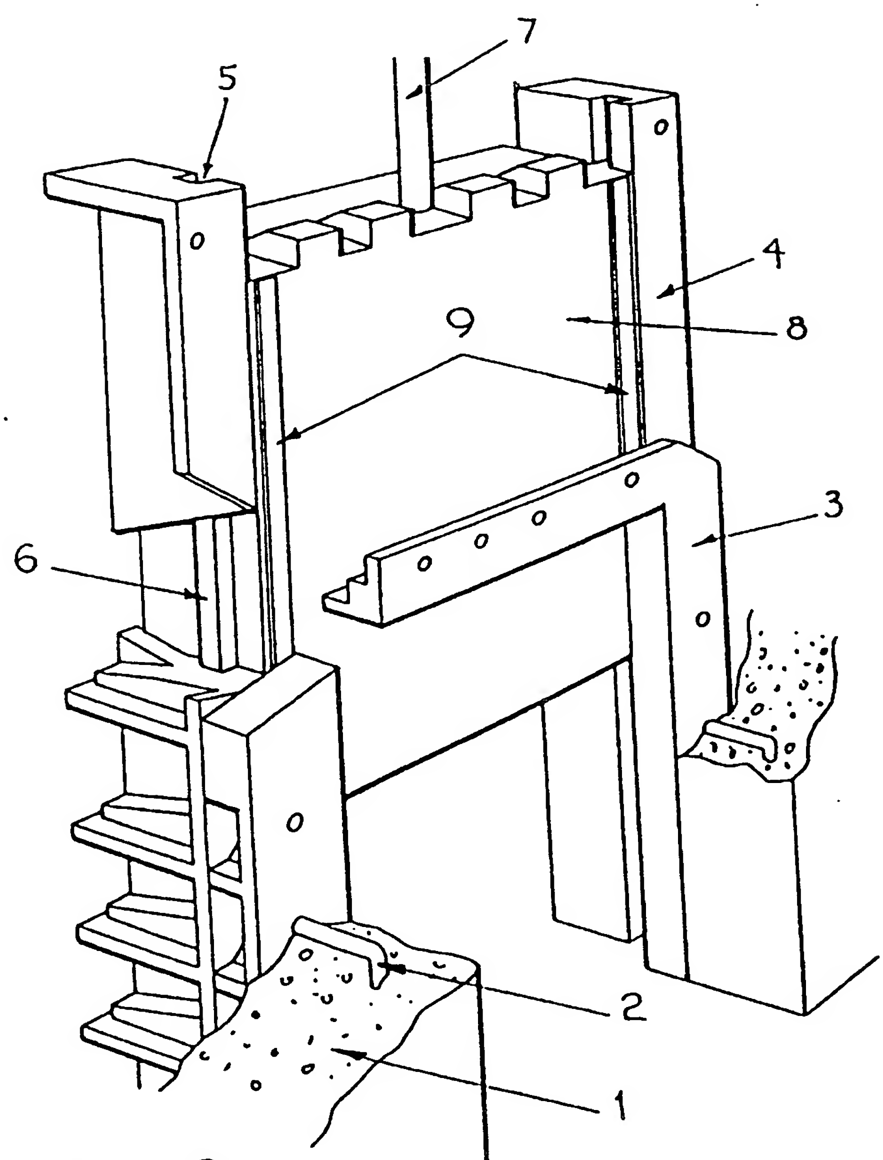

Fig. 9.

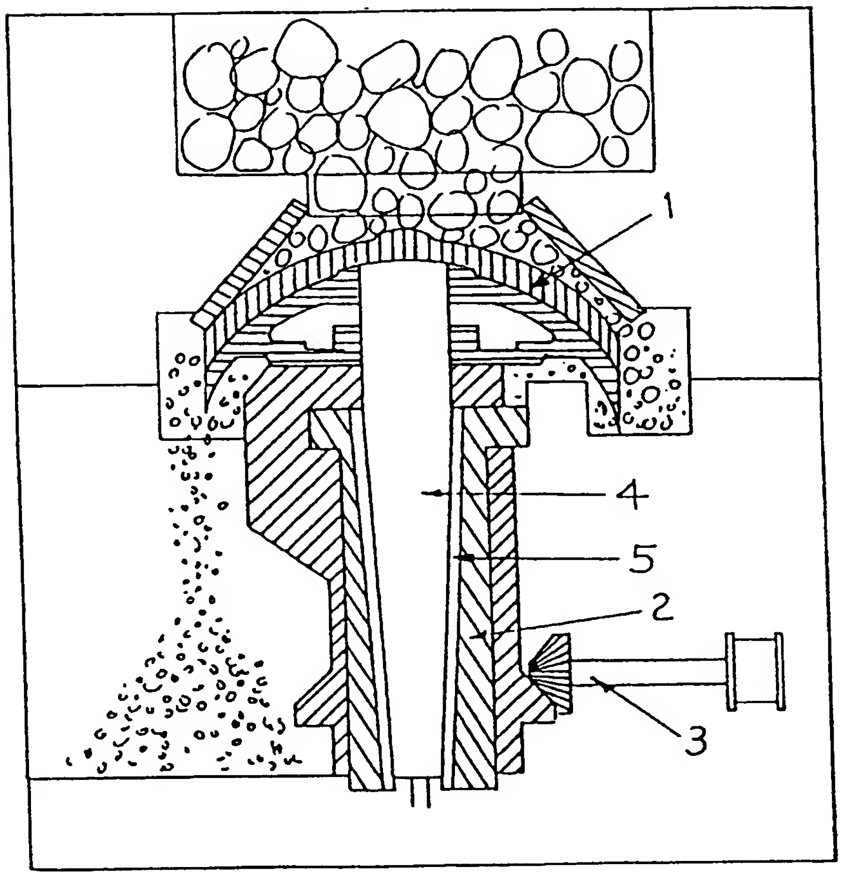

Fig. 10.